COMPOSITION OF THE EJECTA DEPOSITS OF SELECTED LUNAR BASINS FROM CLEMENTINE ELEMENTAL MAPS

Paul D. Spudis[1], B. Ray Hawke[2], P.G. Lucey[2], G.J. Taylor[2], and Karen R. Stockstill[1] 1. Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058 2. Planetary Geosciences, Univ. of Hawaii, Honolulu HI 96822

The composition of basin ejecta can be studied to probe the lunar crust and to understand better the process of large-body impact [1]. Our method uses remote-sensing data to measure the composition of ejecta for many basins of differing sizes, ages, locations around the Moon [2-6]. We have used orbital maps of chemical concentration made by Apollo as well as Earth-based spectra for selected spots within the ejecta. Until now, no basin has had complete coverage of its entire ejecta blanket, as the Apollo groundtracks typically covered a small fraction of the deposit and the telescopic data were 1-2 km diameter spots. Data from the Clementine mission provide global coverage at uniform viewing conditions, resolution, and geometry in a variety of spectral bands in the visible and near-infrared [7]. Recently, Lucey *et al.* [8,9] have reported on a new technique to extract iron and titanium concentrations for the lunar surface from Clementine global images [8,9]. We have used these new maps to provide our first estimate of the mean composition of the ejecta from a variety of near and far side basins. We have compared these estimates to our previous results for parts of the ejecta blanket and are re-examining our previous estimate for bulk crustal composition based on these analyses. Results support the idea that the lunar crust is lower in Fe (i.e., richer in Al) than previously estimated, supporting the concept of a global magma ocean on the early Moon.

Method For this effort, we used existing geological maps [1, 10] and also re-mapped the extent of preserved basin ejecta for each of the basins analyzed. This map was used to make a stencil that was overlain on global maps of Fe [8] and Ti [9], obtained from the Clementine uv-vis images. For each basin deposit, histograms were produced that display the distribution of elemental concentrations, from which mean values were computed (Table 1). These elemental concentrations were compared to previous results for portions of the ejecta observed by the orbiting Apollo spacecraft [11] and used to make inferences about the crust.

Comparison with previous results For several of the basins analyzed, we had previously estimated the elemental compositions of the ejecta from Apollo orbital gamma-ray and X-ray data (summarized in [11]). From Apollo gamma-ray data (which covered only about 30 % of the ejecta area), Orientale basin ejecta appears relatively homogeneous in composition, with FeO contents averaging about 5.8 wt.% and 1 wt.% TiO_2. These values may be compared to the Clementine estimates of 4.1 and 0.3 wt.%, respectively for the entire ejecta blanket. When coverage is restricted to only the Apollo zone, Clementine data indicate an FeO content of 4.3 wt.%, closer to the observed Apollo value of 5.8 wt.% for the same area. The more complete Clementine data for deposits of the Crisium basin show lower FeO (5.1 *v.* 6.2 wt.%) and TiO_2 (0.17 *v.* 0.5 wt.%) compared to the Apollo estimates of only the southern half of the ejecta. Nectaris basin was very poorly covered by Apollo, with only the northernmost strip of highlands overflown, about 10% of its areal extent [3]. Clementine data suggest compositions similar to those estimated from Apollo; FeO (5.1 *v.* 4.8 wt.%) and TiO_2 (0.5 *v.* 0.8 wt.%). The complex and diverse Imbrium basin also shows similarities to earlier estimates of regional composition (Clementine FeO of 9.2 *v.* 11 wt.% and TiO_2 of 0.6 *v.* 2.5-3 wt.%). The higher Apollo values for Ti in the ejecta of Serenitatis and Imbrium probably reflect the inadvertent inclusion of high-Ti mare basalts and pyroclastics in the estimates because of the wide field of view (~200 km) of the gamma-ray detector. In general, compositions estimated from the new elemental maps tend to be somewhat more feldspathic or anorthositic (i.e., Fe- and Ti-poor) than would be suggested from the lower precision Apollo data. This result is congruent with the revised estimate of higher Al in the lunar crust and the Moon in general from the Clementine maps [8].

A First Look at the New Data The new estimates of ejecta composition reflect both the lateral and vertically heterogeneous nature of the crust. Ejecta of smaller basins tend to have lower Fe and Ti contents than do their larger kindred, reflecting the deeper (i.e., more mafic) content of ejecta from basins of larger diameter. However, two relatively small basins appear to have anomalously high Fe and Ti content: Apollo and Humorum (Table 1). The mafic nature of Apollo ejecta may be explained by virtue of its superposition on the floor of the immense South Pole-Aitken basin [10], a feature which probably had already stripped off most of the crustal layer in this part of the Moon prior to the impact which created Apollo [9]. Explaining the high Fe content of Humorum ejecta is more problematical. Determining the true rim crest of Humorum is difficult (similar to the problem of Crisium basin [4])

BASIN EJECTA COMPOSITIONS: Spudis, Paul D. *et al.*

and one possibility is that Humorum may be a much larger basin than 425 km diameter; a case can be made that the topography suggests that the 825 km diameter ring is the real topographic rim of Humorum. On the other hand, we know that ancient mare volcanism has been intensively active in this region [6,12,13] and old mare deposits in this region of the Moon both pre-date and post-date the Humorum basin. Thus, both the high iron and titanium content of Humorum ejecta could reflect the presence of ancient basalts in the deposits, as excavated ejecta, as churned-up, locally mixed secondary crater ejecta, and as partial resurfacing of the basin deposits by pre-Orientale (but post-Humorum) mare lava flows.

Excluding these two anomalies, the general trend is for more mafic ejecta compositions with increasing basin size, as had been previously postulated [1-5, 8]. However, the lateral variation in crustal compositions is also evident; in addition to the anomalous mafic ejecta of two basins, ejecta of the basin Humboldtianum appears to be exceptionally rich in anorthosite (FeO = 2.15 wt.%, corresponding to about 90 percent anorthosite). This observation suggests that the large province of highly feldspathic rocks previously observed [8] is not a surface veneer, but extends to many kilometers depth and reflects the presence of an anorthosite-rich crustal province in the high northern latitudes of the Moon. Such a crustal composition supports the magma ocean model of crustal origin [11].

We have just begun study of basin ejecta compositions using the Clementine global data. Future work will involve analysis of compositional variations in the ejecta as a function of basin size and position from the rim crest, mineralogical composition using the Clementine near-ir camera data [7], and detailed analysis of the topography and gravity of the basins to create a coherent model of basin formation and evolution. We also believe that the new data permit us to refine our estimate of crustal composition and hence, constrain models for the origin and evolution of the Moon.

References [1] Spudis P.D. (1993) *Geology of Multi-ring Impact Basins*, Cambridge Univ. Press, 263 pp. [2] Spudis P.D. *et al.* (1984) *PLPSC* **15**, C197. [3] Spudis P.D. *et al.* (1988) *PLPSC* **18**, 155. [4] Spudis P.D. *et al.* (1989) *PLPSC* **19**, 51. [5] Spudis P.D. *et al.* (1989) *LPS* **XX**, 1042; Spudis P.D. *et al.* (1993) *LPS* **XXIV**, 1341. [6] Hawke B.R. *et al.* (1993) *GRL* **20**, 419. [7] Nozette S. *et al.* (1994) *Science* **266**, 1835. [8] Lucey P.G. *et al.* (1995) *Science* **268**, 1150. [9] Lucey P.G. *et al.* (1996) *Science*, submitted; Lucey P.G. *et al.*, this vol.; Blewett D. *et al.*, this vol. [10] Wilhelms D.E.(1987) *USGS Prof. Paper* **1348,** 301 pp. [11] Heiken G. *et al.* (1991) *Lunar Sourcebook*, Cambridge Univ. Press, Chapter 10. [12] Schultz P.H. and Spudis P.D. (1979) *PLPSC* **10**, 2899. [13] Blewett D. *et al.* (1995) *JGR* **100**, 16959.

TABLE 1. IRON AND TITANIUM CONCENTRATIONS (MEAN ± 1σ) IN BASIN EJECTA

Basin	*Center*	*D (km)*	*FeO (wt.%)*	*TiO_2 (wt.%)*
Orientale	19° S, 95° W	930	4.07 ± 0.43	0.32 ± 0.02
Hertzsprung	2° N, 128° W	570	3.23 ± 0.26	0.23 ± 0.05
Korolev	4° S, 158° W	440	3.44 ± 0.21	0.29 ± 0.03
Apollo	36° S, 151° W	480	8.55 ± 1.28	0.39 ± 0.03
Moscoviense	26° N, 148° E	420	2.70 ± 0.41	0.22 ± 0.04
Mendeleev	6° N, 141° E	365	2.68 ± 0.15	0.15 ± 0.03
Humboldtianum	59° N, 82° E	650	2.15 ± 0.82	0.22 ± 0.05
Smythii	2° S, 87° E	740	4.98 ± 1.56	0.19 ± 0.07
Crisium	18° N, 59° E	740	5.10 ± 1.05	0.17 ± 0.04
Serenitatis	26° N, 18° E	920	8.72 ± 1.26	0.37 ± 0.05
Nectaris	16° S, 34° E	860	5.07 ± 0.84	0.50 ± 0.04
Humorum	24° S, 39° W	425/825*	7.91 ± 1.65	0.98 ± 0.12
Imbrium	35° N, 17° W	1160	9.20 ± 1.34	0.56 ± 0.08

*see text